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A COMPARISON OF REFLEX THRESHOLDS WITH SENSORY THRESHOLDS—THE RELATION OF THIS COMPARISON TO THE PROBLEM OF AT- TENTION

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In a series of papers from this laboratory¹ variations in the sensory threshold for faradic stimulation in man under various conditions have been described. The assumption has been made throughout the series that these variations in threshold result largely from changes in the central nervous system, and that they may be used, therefore as indicators of central nervous changes. The chief basis for this assumption is the observation that the diurnal variations in sensory threshold parallel closely variations in voluntary muscular activity as determined by ergographic fatigue.² Although no theoretical considerations nor any experimental data incompatible with this assumption have come to our attention we have thought it worth while to carry on an investigation designed expressly to test the validity of the use of the sensory threshold as an index of the general state of the nervous system.

The test consisted of repeated comparisons, extending over a considerable period, of the threshold of an easily evoked reflex, the winking reflex, from faradic stimulation of a selected spot on the lower lid, with the sensory threshold for the same spot on the lid. In this comparison the receptors and the afferent pathways as far as the central nervous system are presumably the same for both tests. If our present understanding of the functioning of the nervous system is correct the pathways within the central nervous system must be quite different. That for completion of the reflex would be pictured as a chain of neurones within the brain stem, leading ultimately into the efferent neurones for the muscle

¹ Grabfield and Martin: *American Journal of Physiology*, XXXI, 1913, 300; Martin, Bigelow, and Wilbur: *Idem.*, XXXIII, 1914, 415; Martin, Withington, and Putnam: *Idem.*, XXXIV, 1914, 97.

² Grabfield and Martin: *Loc. cit.*, 308.

of winking; the path for the sensory perception, on the other hand, would be traced into the cortex of the cerebrum.

One would naturally suppose that the cerebral cortex, since it is the most highly organized portion of the nervous system, should also be the most variable. If the sensory threshold is a valid indicator of cortical condition it would be expected to show more pronounced fluctuations from time to time than would the threshold for such an activity as the reflex, which presumably involves less unstable nervous elements.

Method. For applying faradic stimuli one "indifferent" electrode and one stimulating electrode were used. The "indifferent" electrode consisted of a small brass plate about which several layers of absorbent gauze were wrapped. The electrode, well moistened with physiological saline, was applied to the forehead and secured in place by means of bandages about the head. A satisfactory stimulating electrode was secured only after much experimenting with various designs. The one finally used, which gave excellent results, consisted of a short piece of rubber tubing, 7 mm. inside diameter, passed through a hole in a common cork so that about 3 mm. projected beyond the end of the cork. Into the opposite end of the rubber tube from that which projected was inserted an amalgamated metal bar (copper at first, later, for greater durability, zinc). This bar bore a small binding post. It was secured in the tube with sealing wax. The tube next the metal bar was filled with calomel paste. On top of this, and filling the projecting tip of the tube flush to its edge, was a paste of kaolin with salt solution. When the tube filled with this paste was placed in contact with the spot on the lower lid which had been determined experimentally as the best for evoking the wink reflex, the cork rested against the cheekbone, and a simple bandage around the head held it securely in place.

Thresholds were determined quantitatively according to the method developed by one of us.³ Through the kindness of Drs. Southard and Adler, of the psychopathic department of the Boston State Hospital, we were permitted to use the apparatus belonging to that institution for our observations. We take this opportunity of expressing our appreciation of their generosity.

For the routine work of the Psychopathic hospital the complete determination of sensory thresholds in terms of β units⁴ has been found to involve too great a strain upon the

³ Martin: The measurement of induction shocks. New York, 1912.

⁴ Martin: Loc. cit., 76.

patients. For that reason the determination of tissue resistance in each subject is not made, and at the time we were carrying on this investigation the equipment for making resistance measurements was lacking. Our results are in terms of Z units,⁵ therefore, rather than in terms of the more exact β units. For the particular purpose of this study Z units suffice fully, as we shall show later, although there would have been an advantage in being able to express our data in β units, chiefly to make them more readily comparable with the data of other investigations.

Observations. In this work two medical students, P. and W., young men in good health, acted alternately as subjects and observers. Sixty-six readings were made upon W. and 65 upon P. The observations were commenced March 29, 1914, and terminated April 30, 1914. No set time of day was selected for taking readings. On the contrary, it was thought desirable to obtain them at irregular intervals. On some days four readings were made on each subject; on others only one. Two hours was the smallest interval between readings on the same subject.

Save that the region of stimulation was the lower lid instead of the finger tips and that tissue resistances were not measured, the determination of sensory thresholds was according to the method of Grabfield and Martin.⁶ Promptly upon the completion of the sensory determination the subject seated himself directly in front of the observer with his eyes well illuminated, and the threshold of the winking reflex was established. As a matter of fact, the attempt was made to establish two such thresholds, one for the least perceptible movement of the eyelid, and the other for complete closure of the eye. The latter of these was found to be more accurately determinable, and was finally adopted, therefore, as the reflex threshold to be used. Care was taken to avoid errors through mistaking spontaneous winks for those resulting from the test stimuli.

Results. In both subjects the sensory threshold was markedly lower than either of the two reflex thresholds studied. For subject P. the average values of Z from 65 experiments were; sensory threshold, 405; threshold of least perceptible lid movement, 578; threshold of complete closure of eye, 816. For subject W. the average values of Z from 66 experiments were: sensory threshold, 504; threshold of least

⁵ Martin: Loc. cit., 73.

⁶ Grabfield and Martin: Loc. cit., 303.

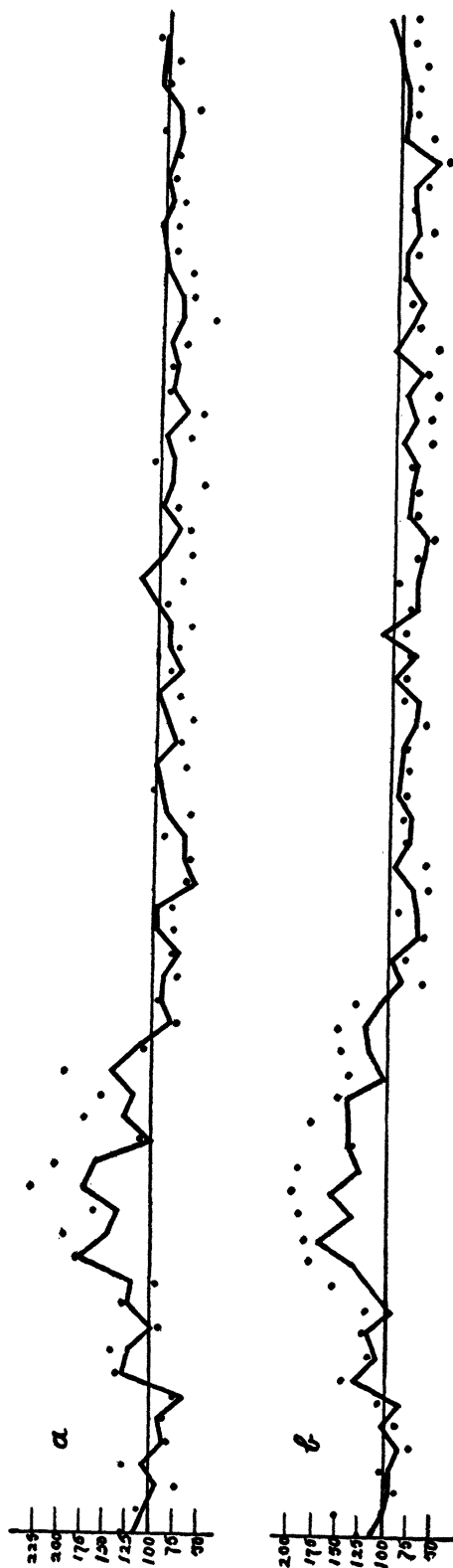


Figure 1. Sensory thresholds compared with reflex thresholds: a, subject P; b, subject W. The thresholds are expressed in terms of percentile divergence from the mean. In each figure a horizontal line is drawn at the level of the mean threshold. The data are set down in chronological sequence. The irregular solid line connects the successive values of the reflex threshold. The dots represent the corresponding sensory thresholds.

perceptible lid movement, 690; threshold of complete eye closure, 990. As one of us has shown elsewhere,⁷ Z units express stimulation strengths only approximately, since they take no account of tissue resistance nor of the manner of electrode contact, although where the general experimental conditions are kept as constant as they were throughout this investigation, the error is not likely to be very large.⁸ However, *relative values* can be accurately stated in Z units so long as secondary resistance and electrode contact remain constant. These conditions were fulfilled in individual experiments of this series. The relation of reflex threshold to sensory threshold *in any given experiment* is therefore accurately known, within the limits of observational error.

If the mean of all values of Z for the sensory threshold of a single subject is determined, and this mean is compared with the value of Z for any single determination, the extent of departure of the individual Z from the mean depends in part upon the fact that the Z unit does not express with entire accuracy the true value of the stimulus, and in part upon an actual difference in threshold of this particular reading as compared with the mean. The same factors enter to account for divergences of individual reflex thresholds from their mean. However, in any given experiment, the extent of divergence, which enters through error in the accuracy of the Z units as expressions of stimulation strengths, must be exactly the same for both sensory and reflex tests. Therefore, if, in any experiment, these observed thresholds show different degrees of divergence from their respective means they are actually as well as apparently, unequally divergent, and the one which, in terms of Z units, appears to be the more divergent, is so actually. Whatever conclusions may legitimately be drawn from study of the relative divergences of the two sorts of thresholds from their respective means are therefore justified.

For convenience and ease of comparison our results are presented in terms of percentages. The method of working these out is that used by Grabfield and Martin.⁹ We have six sets of data; a series of sensory thresholds; a series of thresholds for least perceptible reflex lid movement, and a series of thresholds for complete reflex closure of the eye for each subject. For each set the mean was determined. These mean values are given above, pp. 430ff. The individual

⁷ Martin: American Journal of Physiology, XXVII, 1910, 228.

⁸ Martin: Ibid., 232.

⁹ Grabfield and Martin: Loc. cit., 307.

thresholds were reduced to percentage terms by means of the formula: mean threshold; 100 = individual threshold: \times . By this scheme reflex and sensory thresholds become directly comparable. To bring out the points we wish to make the thresholds for complete reflex closure of the eye are compared with the sensory thresholds. The data from the thresholds for least perceptible lid movement are confirmatory of our conclusions, but the experimental determinations seemed to us less certain, and their inclusion seems not to be essential. Figure 1, a and b, gives the results of our two series, expressed in per cents. In both our subjects the thresholds for the reflex show on the whole markedly less divergence from the mean than do the sensory thresholds. The percentage divergence of any individual reading is simply determined by subtracting its "reduced" value from 100 if it is below the mean, or subtracting 100 from its "reduced" value if it is above. The average of all the percentage divergences thus determined for a single series of thresholds serves as an expression for the "tendency to diverge" of the members of that series. Expressed thus our results are: for reflex thresholds, subject P. 17.3, subject W. 20; for sensory thresholds, subject P. 28.6; subject W. 31. Detailed analysis of our data brings out even more strikingly than do the above averages the greater "tendency to diverge" of sensory as compared with reflex thresholds. Thus in subject P. in 50 out of 65 experiments, and in subject W. in 47 out of 66 experiments the reflex thresholds are nearer the mean than are the corresponding sensory thresholds. The reflex thresholds group themselves, on the whole, within a much narrower range than do the sensory. Thus the range of "reduced" thresholds included between values 75 and 125 contains 77 per cent of the reflex thresholds for P. and 71 per cent for W.; whereas the same range includes only 57 per cent of the sensory thresholds for P. and 50 per cent for W. Of individual thresholds varying from the mean more than 50 per cent the reflex series show only 5, 3 for P, and 2 for W. The sensory series, on the other hand, include 19 such wide divergences, 9 for P. and 10 for W.

The summaries just presented are based upon our entire series of experiments. Reference to the figure shows that through a period of the investigation the thresholds, reflex and sensory, for both subjects were considerably higher than during the remainder of the time. This period of high thresholds began on April third and ended on April tenth. So far as we are aware there was no change in the procedure during

this period, yet various considerations incline us to the belief that an unnoticed variation either in the preparation of the electrodes, their application to the body surface, or the direction of current through them, was the source of the variation in thresholds. The change in thresholds during this period was not duplicated in four other subjects who were making sensory tests with another apparatus at the same time that this investigation was in progress. That the electrodes, and not other parts of the apparatus, were responsible is indicated by the circumstance that on April sixth, in the middle of this period, a set of readings was made on each subject with the apparatus in this laboratory, but with the usual electrodes, brought from the psychopathic hospital for the purpose, and in these readings the high thresholds, characteristic of the period, were recorded.

As we believed the unusual character of these thresholds to be clearly instrumental, we felt justified in including them in our series, since any variations dependent on changes in the apparatus should affect sensory and reflex thresholds alike. To assure ourselves, however, that we were not in error in thus including these unusual thresholds, we have re-examined the two series with the period of high thresholds omitted. The series as thus amended show decidedly lower mean thresholds than those given above (pp. 430ff.). For subject P. the values are: sensory threshold, 51 experiments, 343; reflex threshold 735; as compared with 405 and 816 respectively, for the entire series of 65 tests. For subject W. the mean values from 49 experiments are: sensory threshold, 409, reflex threshold 864, as compared with 504 and 990, from the entire series.

The "tendency to diverge" from the mean is markedly less in magnitude in the amended series, but is still definitely greater for the sensory thresholds than for the reflex thresholds. The figures are: for subject P. reflex thresholds 10.8, sensory thresholds 14; for subject W. reflex thresholds 11.4, sensory thresholds 15.1. In maximal extent of divergence and in number of wide divergences, the sensory thresholds also continue to lead. The greatest reflex divergences are: subject P., 34 per cent, subject W., 36 per cent, as compared with sensory divergences of 52 and 83 per cent, respectively. The range of "reduced" thresholds between values 75 and 125 includes all but 8 per cent of the reflex thresholds for subject P., whereas 18 per cent of his sensory thresholds are without this range. For subject W. the corresponding figures are 6 per cent and 16 per cent respectively.

These results show clearly that in our subjects the threshold for faradic elicitation of the winking reflex is, on the whole, definitely steadier over a considerable period of time than is the electro-cutaneous sensory threshold. Are we justified in interpreting these results as supporting the conclusion that the sensory threshold is a reliable indicator of the general state of the higher nerve centers? An objection which may be urged against such an interpretation, and, in fact, has been so urged by a psychologist with whom the matter has been discussed, is that the fluctuations in sensory threshold may have been due chiefly to variations in the attention of the subject at the different periods of experimentation. Obviously variations in attention cannot be excluded in experiments of this sort. In fact, sensory threshold tests are of necessity in a sense, tests of attention. All that can be done is to instruct the subject to attend as strictly as possible to his part of the procedure. Strong features of this test are that it can be carried out very quickly and that the procedure required of the subject is of the simplest character, so simple, in fact, that the test has been applied successfully to numerous psychopathic cases.¹⁰ The concentration of attention is not rendered difficult by the necessity of following complicated directions, nor is any marked feeling of strain involved. Our experience is that subjects, upon becoming accustomed to the routine, fall into a mental state during the course of individual experiments which seems to be about the same from experiment to experiment. Many psychologists are of the opinion that attention is ordinarily less fluctuating than has formerly been supposed.¹¹ Geissler¹² has shown that fluctuations in the time required for making mental additions agree strikingly with introspective estimates of degree of attention. In his opinion we are entitled, therefore, to base judgments of attention on observed addition times. He presents data from 12 series of experiments without distraction, made on 3 subjects (*loc. cit.*, table II). The greatest fluctuations from average addition time do not exceed 31 per cent, and by far the greater number amount to less than 15 per cent. He found, moreover (*loc. cit.* p. 513), that complex schemes of distraction did not induce great variations in attention. According to these results the variations of sensory threshold due to fluctuations of attention would be expected to be much smaller than those obtained by us in this investigation, and

¹⁰ Grabfield: Boston medical and surgical journal, CLXXI, 1914, 883.

¹¹ See Titchener: Textbook of Psychology. New York, 1910. 291.

¹² Geissler: This Journal, XX, 1909, 508.

we feel that except in so far as the attention is a function of the general nervous state it probably does not enter as a controlling factor in determinations of sensory thresholds by this method.

Certain data from these experiments appear to have a bearing upon the general problem of the fluctuation of attention. In the first place each individual sensory test contains within itself the means of determining whether during its course the attention has fluctuated to a serious extent. This means is afforded through the necessity of determining several thresholds in order that the value of β may be calculated.¹³ If the several calculated β s fail to agree within a reasonable margin (ten per cent is the limit we allow¹⁴), the failure to agree is probably due to a fluctuation of attention. That fluctuations of attention would ever so relate themselves as to conceal their existence is extremely improbable. Determinations have been made in great numbers in this laboratory during recent years, and very seldom, in the hands of experienced workers, must experiments be rejected on account of failure of the calculated β s to agree within ten per cent.

In this particular investigation β units could not be determined because facilities for measuring secondary resistances were lacking, but in each experiment the routine procedure of establishing the usual series of four thresholds was followed, so that the course of the attention during individual experiments could be determined. As a matter of fact the agreement among the different threshold tests of individual experiments is as close in this investigation as in any others that have been carried on in this laboratory, showing that during the period of single experiments (about five minutes) important attention fluctuations have not usually occurred.

Of significance in connection with the problem of the fluctuation of attention from hour to hour and from day to day is the observation that the *direction of divergence* of individual thresholds from the mean was nearly always the same, in any single experiment, for both reflex and sensory thresholds. The two thresholds rose or fell together, but the sensory rose or fell further than the reflex. In only 10 of the 131 experiments were reflex and sensory thresholds on opposite sides of their respective means. In 92 of the 121 experiments in which they were on the same side of the mean the sensory thresholds were further from their means than were the reflex thresholds from theirs.

¹³ Martin: The measurement of induction shocks, 77.

¹⁴ Martin: American Journal of Physiology, XXXVI, 1915, 224.

The fluctuations from their means of the *reflex* thresholds may be taken as a base line. If the sensory thresholds had been found to fluctuate in exact harmony with the reflex thresholds we should have been obliged to conclude that there are no variations in higher brain centers that are not duplicated in lower centers. Had the sensory thresholds fluctuated irregularly about the line traced by the reflex thresholds a simple deduction would have been that variations of attention in the ordinary sense, were responsible. But when the sensory thresholds are seen to follow preponderatingly a course of greater deviation than do the reflex thresholds we feel justified in concluding that something more deep seated is indicated, and that we probably are dealing directly with attention as a function of the condition of the higher brain centers.

SUMMARY

Comparisons in a long series of experiments of threshold stimuli for evoking the winking reflex with sensory threshold stimuli show that the former tend to vary from their mean value definitely less than do the latter.

The observation is made that the "direction of divergence" is nearly always the same for sensory as for reflex thresholds. This is taken to mean that the attention, under the conditions of these experiments, manifests itself as a function of the condition of the higher brain centers.

We draw the general conclusion that the value of the sensory threshold depends on the state of the higher nerve centers, and that the threshold may justly be used, therefore, as an indicator of such nervous state.